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THE MECHANICS OF SOARING.

BY I. LANCASTER.

IT was foreseen that the paper on the soaring birds in the November and December numbers of the NATURALIST of last year would provoke adverse criticism where it dealt with explanations of the movements of those creatures. The recognized laws of the mechanical forces being formulated from data derived from systems of which the earth is a part, makes it extremely difficult to deal with phenomena which are independent of that body, while still existing in its atmosphere.

There arises at every step taken to elucidate the matter, a seeming conflict with accepted laws, and however faultless the reasoning, it is discredited because of that apparent antagonism.

The word "soaring" is also a bad one to name the mechanical actions involved, as it implies a bird. No better, however, is at hand, and it denotes the method employed by the bird and not necessarily the creature itself, as it is here used.

While prosecuting the subject experiments of various kinds were conducted to dispel the obscurity which enveloped it, as careful observations had shown that it was completely different from any other kind of bird flight. Of almost half a hundred theories framed on postulates of bird or air, which were not true, *one* at length was found to be consistent with the facts. I suddenly found myself in the ludicrous predicament of industriously attempting to prove an axiom. My experiments became valueless. Time and means had been wasted. There already existed recognized data to make the whole case self-evident.

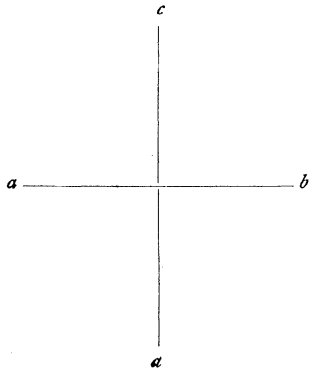
It is now more than five years since the discovery of the mechanical activities herewith detailed. During that time the matter has been made a study in all its bearings, so that mistaken conceptions might be avoided, and it is herewith presented to the mechanical world as worthy of serious attention.

Technically, the material system of soaring is a flat surface, air, and a force. The gravitating force is not essential to it. Any force, a push with the hand, horse-power, steam-power or any other will fill the conditions. Neither is *atmospheric* air essential. The *air* must have the quality of great elasticity and offer considerable resistance to a moving body which compresses or drives it out of the way, and very little to the passage of a smooth, flat surface like a sheet of tin, edgeways in it. The force is then applied to the body in such a way as to move it at right angles to the direction in which the force acts. This translation of the body is "soaring." It rests on two universally recognized laws. The most important is the conservation of energy, of which it is the most beautiful illustration to be found in mechanics. The other is the reaction in all directions of fluids under the action of mechanical forces.

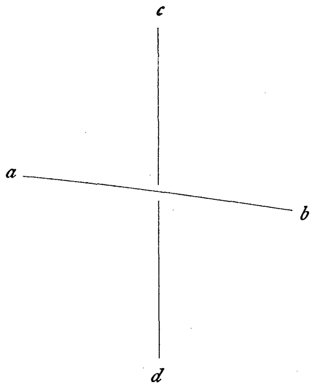
The body must be so constructed as to have at least two directions of motion which are unequally resisted by the air.

The case will be first presented as operating in space devoid of gravitation, where the body will have no weight, and afterwards the system will be introduced into the earth's atmosphere. Implications arising from the action of gravity, and the constant tendency to introduce the earth into the soaring system, will be avoided.

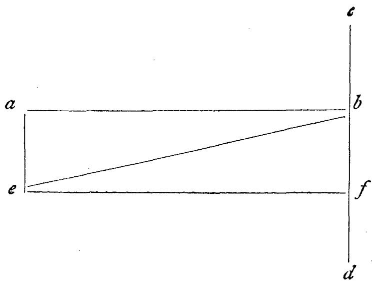
Suppose the body to be an oblong flat surface, such as a sheet of tin 12 × 72 inches, and that *a b* is its transverse section, and that the force moves from *c* towards *d*, at right angles to the sides of the surface.



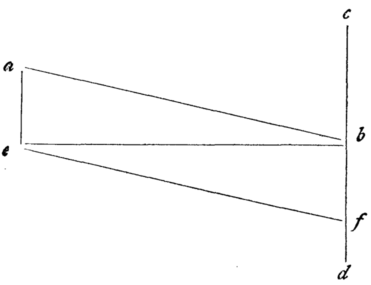
Surface at right angles to the direction of the force.



Surface inclined to the direction of the force.



Lateral motion of surface at right angles to the force.



Lateral motion of surface inclined to the force.

That the value of the force is twelve pounds moving the surface on the air with uniform velocity, which we will suppose to be five feet per second. Under these conditions it is obvious that all the force is employed in condensing and otherwise disturbing air, so that it is doing work on the air at the rate of twelve pounds each second. It is also obvious that while uniform velocity occurs there is a moving equilibrium between the surface acted on by the force and the reacting air, and that any additional force, however small, applied to the surface at any angle to its own plane would disturb this balance, and either accelerate or retard its velocity. If, however, the additional force be applied in its plane, lateral motion would occur without changing the equilibrium. In the lateral motion no air is disturbed, nor driven out of the way, nor condensed, excepting what is caused by smooth skin, or surface friction, and this is so very small as to elude all my attempts to find its value. One pound applied in the plane of the surface would doubtless drive it at the rate of 1000 feet per second. We will suppose, however, that one pound will drive it from *b* towards *a* at the rate of thirty feet per second. As it is moving towards *d* at the rate of five feet per second, it will pass neither towards *d* nor *a*, but on the diagonal *b e*, the resulting path, the parallelogram being thirty feet long and five feet wide.

Note the character of the equilibrium between the surface and air. The total force is flowing around the edges of the surface in the shape of condensed and otherwise disturbed air. If the hand were placed under the surface with an upward push, precisely as much resistance as would be *given to* the hand would be *taken from* the air, and the velocity retarded. If scales were applied to the surface and a pull towards *c* given, part of the force would be moving the index and precisely that much less would be working on air, and the velocity of the surface would be again retarded. If the surface met with sufficient impediment to stop its motion, *all* the force would be resisting the impediment and *none* doing work on air, and velocity would cease.

It is evident that at uniform velocity the force has been transferred. It is in the air tension, and not in the surface, for to be also there, would necessitate its creation out of nothing. There being then, no force in the surface, it could not antagonize any resistance offered to it, and this is in fact its condition as we have seen. While its velocity remained uniform it would obey any impulse derived from incident forces directed upon it, being powerless to resist them.

So far all is evident, but the surface would not fill the conditions of soaring. Its motion is not at right angles to the force, but inclined thereto, and to accomplish the desired result its path must be perpendicular to the force.

If we now tilt the surface on one of its long edges, *b*, say for two inches, or one in six, it would no longer follow the direction of the force, but slant sideways towards this edge. Following the law of the composition of forces, one-sixth of the force, or two pounds, will now drive the surface sideways, and there being nothing but trifling skin friction to oppose it, it will obey the impulse. But if we apply a force of two pounds to the edge to balance this thrust, equilibrium will once more occur and the surface will move in the path of the force. Experimentally, far less than two pounds is required for this rest, as a considerable incline is reached before the sideways thrust is developed, the confused air currents under the surface obscuring the movement.

Note that this abutting force is of the nature of pressure. It is a static feature devoid of motion. It is a rest for the tilted surface to lean against.

It cannot be denied that we now have a case of equilibrium once more. With the two-pound rest a perfect balance results and the surface moves in the path of the force. All the force is disturbing air, while the surface moves with uniform velocity. *At that speed* it is unable to offer the least resistance to any further force which may be opposed to it. At this point the answer to a single question will be decisive. If it be in the affirmative the position is secure; if in the negative, my explanation of soaring is wrong, the birds are still in the air waiting solution.

The question is this: Will the tilted surface, supplied with the rest of two pounds and moving with uniform velocity, obey the impulse of an external force, applied in its own plane, with equal facility in any direction?

It certainly is evident that the only resistance to such a force arises from skin friction in whatever way the motion is made. If there be any other from whence comes it? It cannot come from the original force, for this is fully employed. It cannot come from the two-pound rest, as this is already balanced by the sideways thrust of the reacting air. This does not vary with the velocity in the plane of the surface. It is two pounds at all velocities; motion in the plane of the surface does not change the *value* of the condensations, but only their *character*. It makes them thinner but wider, the total of twelve pounds being constant at all velocities; so that the two-pound abutment can only vary with the inclination of the surface to the direction of the force. It is obvious that a force applied to the surface in the direction of its length, will move it either way indifferently. It can be seen at once that the two-pound rest will not resist such a force at any velocity whatever in these directions. Leaving unnoticed any oblique motion neither longitudinal nor transverse, the important point is, will a given force, say of one pound, move the surface towards *a*, with the same velocity as towards *b*?

It is possible that when the lateral motion is set up there might be developed in the air disturbances, differences which would require an increase or diminution of velocity towards *d*, to balance the twelve pounds, and that these differences would be greater or less towards *b* than *a*. But this would in no way affect the lateral motion. Acceleration or retardation would go on until equilibrium again occurred, so that it would be a balanced surface which is moved. The vital point is: Does or can the twelve pounds in any way resist the lateral motion either towards *a* or *b*? It seems evident that there is no conceivable way in which the lateral motion in either of these directions can be resisted by the twelve-pound force, under these conditions, without at once traversing the law of the conservation of energy. The only resistance to be found is the skin friction on six square feet of smooth surface under a pressure of two pounds to the foot.

If this be a fact the case is proven. There is no other feature of it which would be denied.

Note the implications of the case. The lateral motion caused by the one pound would now carry the surface to *b*, while it is going to *d*, and it would pass to *c*, at right angles to the twelve-pound force. In going thirty feet laterally it moves sixty inches *contrary* to the direction of the force of twelve pounds and sixty inches *with* that direction, so that its path is at right angles to it. The motion of sixty inches *contrary* to the force is a function of the lateral motion and does not resist the force in the remotest manner; while motion of sixty inches *with* the force, towards *d*, is the direct result of this force. While the lateral motion is going on at the rate of thirty feet per second, twelve pounds per second of air disturbance is flowing past the edge *b*, while but three pounds is required to give the lateral thrust and furnish the two-pound rest. If this edge be rounded upwards along its seventy-two inches of length to serve as a base for the expanding air to act against, it will give the needed three pounds and still leave nine pounds to go to waste by falling to the tension of the surrounding air. With this substitution the soaring action is complete. The force is now translating the body at right angles to its own direction. It will be noted that a velocity towards *a* greater than thirty feet per second will cause the surface to move *contrary* to the direction of the force faster than *with* it. Also, if a greater inclination be supposed, the abutting force would be greater, and the above contrary motion augmented. A limit would soon be reached in this direction, however. At an incline of one to four the rest would be three pounds, at one to three, four pounds, which latter would pass the limit of soaring, as it would require a rear expansion of five pounds to effect lateral motion, a utilization of five-twelfths of the entire force, which would surpass the ability of the system.

A single further peculiarity is to be noted. Suppose the indefinite body of air belonging to this system to be in motion, either *with*, or *against*, or at any angle whatever to the direction of the force. The action of the parts of the system would remain unaffected by such motion. It is universally recognized that the translation of a system as a whole has no effect on the interaction of its parts.

Let us now suppose the motion of the body of air containing the system be towards the earth's atmosphere in a direction tangential to its surface, at the rate of one hundred miles per hour, until the air of the system and the atmosphere became identical, we would have a bird soaring in wind of that velocity, and this wind, or any other wind, or a dead calm, or wind vertically downwards, or upwards, or at any other angle, are identical states of air so far as the soaring system is concerned.

In the earth's atmosphere, surface and air will remain the same, while the force will be that of gravity. The surface *now* has weight. It is a body plus a force, and the entire matter is the same that we have been considering. The surface is a soaring bird. It is an inert body translated at right angles to the gravitating force, or horizontally, and solely by the action of that force. It has constant motion in the direction of gravity but does not lose its energy of position by getting nearer the earth. It resembles *in this respect* a clock moved by a weight, and placed on the platform of an elevator which slowly ascends. While the clock weight is a falling body having motion in the direction of gravity, it still does not lose its energy of position by getting nearer the earth, because of another motion in which it is elevated.

The surface, under the action of this force as above conditioned, is a splendid atmospheric highway maker. It lays down an endless cushion of air on which it travels with incredible speed. It is paralleled by nothing in nature. It is gravity in the rôle of a continuous motive power. It obeys implicitly the laws of mechanics in every particular, and gives man complete dominion of the air.

When the attention is directed to soaring in the earth's atmosphere, as exhibited by the birds, two delusions must be industriously guarded against. One is that wind is concerned in the phenomenon. The other is that the horizontal motion of flight is the result of a single impulse acting in one direction.

When it is seen that motion is derived from gravitating force exhibited by the quiescent bird in all cases, and that its level flight is a compound result of two motions, one vertically downwards, and one slanting upwards in the plane of the wing surfaces, both simultaneously occurring, the subject assumes a more explicable form.

Then when it is seen that no weight is lifted in the upward slant, this action bearing no resemblance to a ball rolled up an inclined plane, the case will be in a fair way to be completely comprehended.

In conclusion, I may be pardoned for indicating the direction in which criticism of this paper may be fruitful.

It is easy to lose oneself in the limbo of a vicious terminology. To show that expressions in regard to the gravitating force being "a continuous motive power," and conferring on it other unusual abilities not hitherto recognized, are unwarranted, is not to weaken the case. It will merely show an improper use of words.

Statements of fact regarding the plane inclined to the force, and culminating in the possibility of equal ease of motion in any direction under the conditions given, contain the vital elements.

As an explanation of soaring birds the facts of the transformation of gravity into air disturbance, and the results flowing therefrom as stated, are pertinent. To invalidate that explanation it must be shown :

1. That such transformation does not take place.
2. That no such results as those given are possible.

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THE STONE AX IN VERMONT.[1]

BY PROFESSOR GEO. H. PERKINS.

II.—NOTCHED AND GROOVED AXES.

IN all our collections we find a few axes which are notched or grooved across the narrow sides. They are not common in any portion of Vermont, nor, if we may judge from what has been published by various writers, do they appear to be abundant anywhere in the United States.

As was noticed in the preceding article we are able to arrange our specimens in such a manner that there is a very complete series from the simplest celt, through the notched ax, to the fully grooved ax, and it seems quite probable that the notched ax was the second step in the development of the ax from the simply edged pebble. The form of the notched ax is more like that of the common celt than is that of the grooved ax. In fact some of the notched axes are nothing else than celts notched at the sides, and they are never so large and heavy as are many of the grooved axes.

A type of these axes is shown in Fig. 1, which represents a common form, about one-half the natural size.

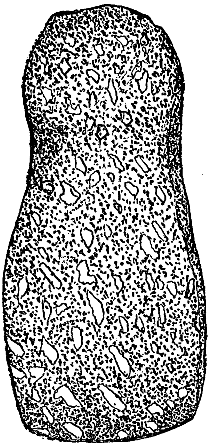

FIG. 1.

As a rule these axes are not more than four or five inches long and two or three wide. They are usually well shaped, neither rude nor clumsy, and the surface is smooth or perhaps polished. The form of some is such as to suggest the adze, and it seems quite likely that an implement so useful in hollowing canoes and

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[1] Continued from p. 1149, December number, 1885.